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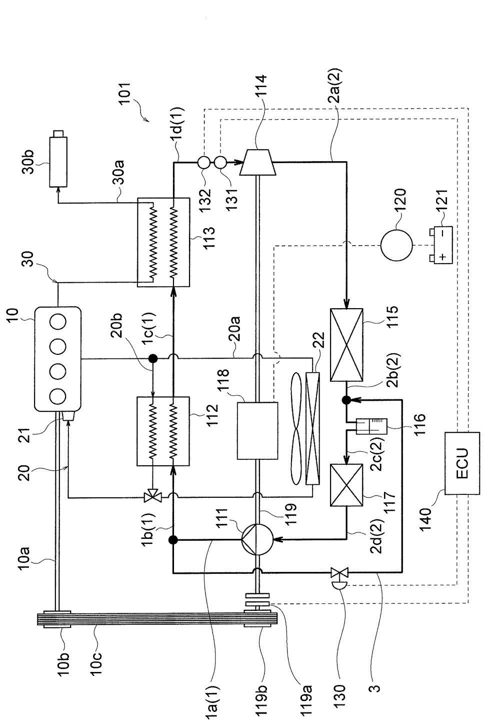
(54) RANKINE CYCLE

(57) A Rankine cycle 101 where, in a circulation channel of a refrigerant, a waste gas boiler 113 exchanging heat between the refrigerant and exhaust gas, an expander 114, a condenser 115 and a pump 111 are provided in order, includes a temperature sensor 131 sensing the temperature of the refrigerant flowing out of the waste gas boiler 113, a pressure sensor 132 sensing the pressure of the refrigerant flowing through the waste gas boiler 113, a bypass flow channel 3 and a flow rate regulating valve 130 for adjusting the refrigerant flow rate to the waste gas boiler 113 and an ECU 140 controlling the flow rate regulating valve 130. The ECU 140 controls to change the temperature and pressure of the refrigerant sucked into the expander 114 while satisfying the relationship along the target pressure line TPL where the target pressure is set to increase the refrigerant density following the increase in the refrigerant temperature.

FIG.1



EP 2 728 131 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a Rankine cycle.

BACKGROUND ART

[0002] Techniques using a Rankine cycle that converts heat discharged from an internal combustion engine of a vehicle into power for an electric generator or the like have been developed.

[0003] The Rankine cycle is constituted by a heat exchanger that converts a working fluid into superheated vapor by causing heat exchange between a heat medium containing heat discharged from the internal combustion engine and the working fluid, an expander that obtains power by causing the working fluid in the superheated vapor state to expand, a condenser that cools and liquefies the expanded working fluid, a pump that pumps the liquefied working fluid to the heat exchanger, etc. By expanding the working fluid, the expander rotates a rotating body such as a turbine. As a result, the energy during the expansion of the working fluid is converted into the rotational driving power, and the rotational driving power is transmitted as power to an electric generator or the like.

[0004] For example, Patent Document 1 describes a Rankine cycle in which a first heat exchanger that causes heat exchange between a refrigerant (working fluid) and cooling water of an internal combustion engine, and a second heat exchanger that causes heat exchange between the refrigerant and exhaust gas (heat medium) of the internal combustion engine are disposed in the order of description in a flow channel by which a refrigerant pump feeds the refrigerant to an expander. In the Rankine cycle described in Patent Document 1, the refrigerant is evaporated by heat exchange with the cooling water in the first heat exchanger and then converted into superheated vapor by heat exchange with exhaust gas having a higher temperature in the second heat exchanger. The superheated vapor flows into the expander.

PRIOR ART DOCUMENT

PATENT DOCUMENT

[0005] Patent Document 1: Japanese Patent Application Laid Open No. 2011-12625

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0006] In the Rankine cycle described in Patent Document 1, the temperature of the exhaust gas changes significantly within a range of from about 200°C to about 800°C according to the load on the internal combustion engine and becomes very high. As a result, the refrigerant undergoing heat exchange in the second heat exchanger absorbs a larger amount of heat and is heated to a higher temperature following the increase in the exhaust gas temperature, and the high-temperature refrigerant is sucked into the expander. Accordingly, a problem associated with the Rankine cycle described in Patent Document 1 is that a heat-resistant design is required for the expander, refrigerant piping, etc., and the cost is therefore increased.

[0007] It is an object of the present invention to resolve this problem and provide a Rankine cycle in which the increase in the refrigerant temperature related to the increase in the exhaust gas temperature is inhibited in heat exchange between the refrigerant (working fluid) and the exhaust gas (heat medium).

MEANS FOR SOLVING THE PROBLEM

[0008] In order to solve the abovementioned problem, the present invention provides a Rankine cycle where, in a circulation path of a working fluid, a heat exchanger that implements heat exchange between the working fluid and a heat medium, a fluid expander that generates driving power by expanding the working fluid, a condensing unit that condenses the working fluid and a fluid pumping device that transfers the working fluid to the heat exchanger are provided in order, wherein the state of the working fluid after the heat exchange with the heat medium in the heat exchanger is superheated vapor, the Rankine cycle including: a temperature detector that detects the temperature of the working fluid flowing out of the heat exchanger; a pressure detector that detects the pressure of the working fluid flowing through the heat exchanger; flow rate adjusting means for adjusting the flow rate of the working fluid into the heat exchanger; and a control device that controls the flow rate adjusting means, wherein the control device sets a target pressure such that the density of the working fluid flowing out of the heat exchanger increases following an increase in the temperature detected by the temperature detector, and controls the flow rate adjusting means so that the detected pressure of the pressure detector becomes the target pressure.

ADVANTAGEOUS EFFECT OF THE INVENTION

[0009] With the Rankine cycle in accordance with the present invention, the increase in the working fluid temperature related to the increase in the heat exchange amount in the heat exchange between the working fluid and the heat medium can be inhibited.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIG. 1 is a schematic diagram of a Rankine cycle according to an embodiment of the present invention and the peripheral configuration thereof.

FIG. 2 is a p-h diagram illustrating the state of the refrigerant in the Rankine cycle shown in FIG. 1.

FIG. 3 illustrates a modification example of the Rankine cycle according to the embodiment.

FIG. 4 illustrates another modification example of the Rankine cycle according to the embodiment.

MODE FOR CARRYING OUT THE INVENTION

[0011] An embodiment of the present invention is described hereinbelow with reference to the appended drawings.

Embodiment

[0012] First, a Rankine cycle 101 according to an embodiment of the present invention and the peripheral configuration thereof are explained. In the below-described embodiment, an example is explained in which a Rankine cycle is used in a vehicle carrying an internal combustion engine, that is, an engine 10.

[0013] Referring to FIG. 1, the vehicle (not shown in the figure) equipped with the engine 10 is provided with the Rankine cycle 101.

[0014] In the Rankine cycle 101, a circulation channel is formed in which a pump 111, a cooling water boiler 112, a waste gas boiler 113, an expander 114, a condenser 115, a receiver 116, and a sub-cooler 117 are successively connected annularly, and a refrigerant (R134a in the present embodiment) which is a working fluid flows therethrough.

[0015] When operating, the pump 111 pumps a fluid, in the present embodiment, a liquid. The pump 111 shares a drive shaft 119 thereof with the expander 114. A pulley 119b is also linked by an electromagnetic clutch 119a to the drive shaft 119. The pulley 119b is linked by a drive belt 10c to an engine pulley 10b linked to an engine drive shaft 10a extending from the engine 10. The electromagnetic clutch 119a can connect and disconnect the drive shaft 119 and the pulley 119b and is electrically connected to an ECU 140, which is a control device of the vehicle, so that the connection/disconnection operation thereof could be controlled by the ECU 140. Therefore, the rotational speed of the pump 111 depends on the rotational speed of the engine 10 or the expander 114.

[0016] Here, the pump 111 constitutes a fluid pumping device.

[0017] A discharge port located downstream of the pump 111 communicates via flow channel sections 1a and 1b with a refrigerant inlet of the cooling water boiler 112. The refrigerant and cooling water for cooling the engine which flows in a cooling water circuit 20 of the engine 10 flow through the inside of the cooling water boiler 112 and exchange heat with each other, thereby making it possible to heat the refrigerant.

[0018] In the cooling water circuit 20, a radiator 22 is provided in an intermediate section of a water circulation flow channel 20a which is a circulation flow channel extending from the engine 10 and connected to a water pump 21 integrated with the engine 10, and the cooling water boiler 112 is provided in an intermediate section of a branched water flow channel 20b that branches off in an intermediate section of the water circulation flow channel 20a and merges again with the water circulation flow channel 20a. The radiator 22 cools the cooling water by heat exchange between the surrounding air and the cooling water flowing through the inside thereof.

[0019] A refrigerant outlet of the cooling water boiler 112 communicates with a refrigerant inlet of the waste gas boiler 113 through a flow channel section 1c. The refrigerant flowing from the cooling water boiler 112 and the exhaust gas of an exhaust gas system 30 of the engine 10 flow through and exchange heat with each other inside the waste gas boiler 113, thereby making it possible to heat the refrigerant. The waste gas boiler 113 is interposed in an intermediate section of an exhaust gas flow channel 30a communicating the engine 10 with a muffler 30b in the exhaust gas system 30.

[0020] Here, the exhaust gas constitutes a heat medium, and the waste gas boiler 113 constitutes a heat exchanger.

[0021] A refrigerant outlet of the waste gas boiler 113 communicates through a flow channel section 1d with an inlet of the expander 114 which is a fluid expander. The expander 114 is a fluid apparatus that causes in the inside thereof expansion of the high-temperature and high-pressure refrigerant heated in the waste gas boiler 113, thereby rotating the drive shaft 119 together with the rotating body such as a turbine and thus producing work defined by the rotational drive power. An alternator 118 having a power generating function is provided between the expander 114 and the pump 111, and the alternator 118 also shares the drive shaft 119. Therefore, the rotational drive power generated by the expander 114 can integrally drive the alternator 118 and the pump 111 through the drive shaft 119, and the drive power of the pump 111 imparted by the engine 10 can integrally drive the alternator 118 and the expander 114 through the drive shaft 119.

[0022] The flow channel sections 1a, 1b, 1c, and 1d constitute a first flow channel 1 which is a high-pressure-side flow channel of the refrigerant.

[0023] The alternator 118 is electrically connected to a converter 120, and the converter 120 is electrically connected to a battery 121. Where the expander 114 rotationally drives the drive shaft 119, the alternator 118 generates an AC current, and supplies the generated current to the converter 120. The converter 120 converts the supplied AC current into a DC current and charges the battery 121 with the converted current.

[0024] The outlet of the expander 114 communicates with the inlet of the condenser 115 through a flow channel section 2a. The refrigerant flows through the inside of the condenser 115 and exchanges heat with the air surrounding the condenser 115, thereby making it possible to cool and condense the refrigerant.

[0025] Here, the condenser 115 constitutes a condensing unit.

[0026] The outlet of the condenser 115 communicates with the inlet of the receiver 116 through a flow channel section 2b, and the outlet of the receiver 116 communicates with the inlet of the sub-cooler 117 through a flow channel section 2c.

[0027] The receiver 116 is a gas-liquid separator including liquid refrigerant inside thereof and serves for removing, for example, a vapor component of the refrigerant, moisture and foreign matter contained in the refrigerant.

[0028] The liquid refrigerant supplied from the receiver 116 flows through the inside of the sub-cooler 117 and exchanges heat with the air surrounding the sub-cooler 117, thereby making it possible to supercool the refrigerant.

[0029] The outlet of the sub-cooler 117 communicates with the suction port of the pump 111 through a flow channel section 2d, and the refrigerant flowing out from the sub-cooler 117 is sucked into the pump 111, pumped again and circulated in the Rankine cycle 101.

[0030] The flow channel sections 2a, 2b, 2c, and 2d constitute a second flow channel 2 which is a low-pressure-side flow channel of the refrigerant.

[0031] The Rankine cycle 101 has a bypass flow channel 3 communicating the flow channel section 1a of the first flow channel 1 with the second flow channel 2. In the present embodiment, one end of the bypass flow channel 3 is connected to the connection portion of the flow channel section 1a and the flow channel section 1b of the first flow channel 1, and the other end of the bypass flow channel 3 is connected to the flow channel section 2b of the second flow channel 2. Further, the Rankine cycle 101 has a flow rate regulating valve 130 in the intermediate section of the bypass flow channel 3, with this flow rate regulating valve capable of opening or closing the bypass flow channel 3 and adjusting the cross-sectional area of the bypass flow channel 3. The flow rate regulating valve 130 is electrically connected to the ECU 140 and the operation thereof can be controlled by the ECU 140.

[0032] Here, the bypass flow channel 3 and the flow rate regulating valve 130 constitute a flow rate adjusting means.

[0033] The Rankine cycle 101 also has a temperature sensor 131 that senses the temperature of the refrigerant flowing through in the flow channel section 1d and a pressure sensor 132 that senses the pressure of the refrigerant flowing through in the flow channel section 1d, in the vicinity of the inlet of the expander 114 in the flow channel section 1d of the first flow channel 1. The temperature sensor 131 senses the temperature of the refrigerant in the inlet of the expander 114, that is, the temperature of the refrigerant flowing out of the waste gas boiler 113, and sends the sensed temperature information on the refrigerant to the ECU 140 electrically connected thereto. The pressure sensor 132 senses the pressure of the refrigerant in the inlet of the expander 114, that is, the pressure of the refrigerant flowing through the waste gas boiler 113, and sends the sensed pressure information on the refrigerant to the ECU 140 electrically connected thereto. In the flow channel sections 1a to 1d of the first flow channel 1, the pressure of the refrigerant is the same between the flow channel sections, regardless of whether the flow rate regulating valve 130 is opened or closed. Therefore, the pressure sensor 132 may be provided in any of the flow channel sections 1a to 1c.

[0034] Here, the temperature sensor 131 constitutes a temperature detector, and the pressure sensor 132 constitutes a pressure detector.

[0035] The operation of the Rankine cycle 101 according to the embodiment of the present invention is described below.

[0036] Referring to FIG. 1, while the engine 10 is operating, the water pump 21 also operates and pumps the cooling water. The cooling water pumped from the engine 10 to the outside circulates so as to flow through the cooling water boiler 112 and the radiator 22 in the cooling water circuit 20 and return again to the engine 10.

[0037] The exhaust gas is discharged from the operating engine 10 into the exhaust gas system 30. After the discharged exhaust gas flows through the inside of the waste gas boiler 113, it is discharged to the outside of the vehicle from the muffler 30b.

[0038] If the engine 10 is operated, the ECU 140 connects the electromagnetic clutch 119a. As a result, the rotational drive power of the engine 10 is transmitted by the engine drive shaft 10a, engine pulley 10b, drive belt 10c, pulley 119b and electromagnetic clutch 119a to the drive shaft 119. As a result, the drive shaft 119 integrally drives the pump 111, the alternator 118 and the expander 114.

[0039] The driven pump 111 pumps the refrigerant in a liquid state towards the cooling water boiler 112. The driven expander 114 rotates the rotating body such as a turbine to reduce the pressure of the refrigerant in the flow channel section 1d of the first flow channel 1 and feed the refrigerant to the flow channel section 2a of the second flow channel 2. As the refrigerant is pumped by the pump 111, the refrigerant is subjected to adiabatic pressurization.

[0040] The refrigerant in a liquid state that has been pumped by the pump 111 flows through the flow channel sections 1a and 1b into the cooling water boiler 112 and exchanges heat with the cooling water flowing through the inside thereof. As a result, the refrigerant undergoes isobaric heating, the temperature thereof rises, and the refrigerant flows out. When the flow rate regulating valve 130 is open, part of the refrigerant in the flow channel section 1a merges through the bypass flow channel 3 with the flow channel section 2b of the second flow channel 2.

[0041] The refrigerant that is discharged out of the cooling water boiler 112 flows through the flow channel section 1c into the waste gas boiler 113 and exchanges heat with the exhaust gas flowing through the inside of the boiler 112. As a result, the refrigerant undergoes isobaric heating, the temperature thereof rises, and refrigerant converted into high-temperature and high-pressure superheated vapor is discharged.

[0042] The refrigerant in the high-temperature and high-pressure superheated vapor state, which has been discharged out of the waste gas boiler 113, is sucked into the expander 114 through the flow channel section 1d. The refrigerant adiabatically expands in the expander 114 by using the difference in refrigerant pressure between the flow channel section 1d on the upstream side and the flow channel section 2a on the downstream side, and then is discharged in a high-temperature low-pressure superheated vapor state. Further, in the expander 114, the expansion energy of the refrigerant is converted as regenerated energy into rotational energy and transmitted to the drive shaft 119.

[0043] The regenerated energy transmitted to the drive shaft 119 is not only applied as rotational drive power to the alternator 118 and the pump 111, but is also transmitted to the engine 10 and assists the rotational drive thereof. Further, the alternator 118 is operated by the applied rotational drive power to generate an AC current. The generated AC current is converted by the converter 120 into a DC current and charges the battery 121.

[0044] The refrigerant in the superheated vapor state that is discharged out of the expander 114 flows through the flow channel section 2a into the condenser 115. In the condenser 115, the refrigerant is isobarically cooled and condensed into a liquid state by heat exchange with the surrounding air, that is, the ambient air. Thereafter, the refrigerant is discharged out of the condenser 115.

[0045] The refrigerant in a liquid state that has been discharged out of the condenser 115 flows through the flow channel section 2b into the receiver 116. Further, the refrigerant passes through the liquid refrigerant stored inside the receiver 116 and is discharged into the flow channel section 2c. When the refrigerant passes through the inside of the receiver 116, vapor components of the refrigerant, moisture, and foreign matter contained therein are removed.

[0046] The refrigerant that has been discharged out of the receiver 116 flows through the flow channel section 2c into the sub-cooler 117. In the sub-cooler 117, the refrigerant is further isobarically cooled into a supercooled liquid state by heat exchange with the ambient air and flows out into the flow channel section 2d. Then, the refrigerant in the flow channel section 2d is sucked into the pump 111, pumped again, and circulated in the Rankine cycle 101.

[0047] Here, in FIG. 2, state transformations of the refrigerant in the circulation process of the Rankine cycle 101 are shown on a p-h diagram of the refrigerant. The p-h diagram has an orthogonal coordinate system in which the pressure of the refrigerant (in MPa units) is plotted against the ordinate, and the refrigerant enthalpy (in kJ/kg units) is plotted against the abscissa. Further, the region in which the refrigerant is in the supercooled liquid state is shown by a supercooled liquid region SL, the region where the refrigerant is in the wet vapor state is shown by a wet vapor region WS, and a region where the refrigerant is in the superheated vapor state is shown as a superheated vapor region SS. A saturated liquid line α is shown on the boundary of the supercooled liquid region SL and the wet vapor region WS, and a dry saturated vapor line β is shown on the boundary of the wet vapor region WS and the superheated vapor region SS.

[0048] Further, in FIG. 2, state transformations of the refrigerant circulating in the Rankine cycle 101 in a state with a median load on the engine 10 (see FIG. 1) and with an average temperature of the exhaust gas in the operation of the Rankine cycle 101 (for example, about 500°C to about 600°C) proceed along a cycle S having a trapezoidal shape with points A, B, C and D as apexes.

[0049] When viewed in conjunction with FIG. 1, the process from point A to point B in the cycle S is adiabatic pressurization of the refrigerant by pumping with the pump 111. In this process, the pressure of the refrigerant is raised from pressure Pa to pressure Pb, the temperature thereof is also raised, and the liquid state thereof (supercooled liquid state) is maintained inside the supercooled liquid region SL.

[0050] In the process from point B to point C, the process from point B to point E represents isobaric heating in the cooling water boiler 112, and the process from point E to point C represents isobaric heating in the waste gas boiler 113. In the process from point B to point E, by heat exchange with the cooling water, the temperature of the refrigerant is raised, while the pressure thereof is maintained at Pb. In the process from point E to point C, by heat exchange with the exhaust gas, the temperature thereof is further raised to reach To, while the pressure thereof is maintained at Pb. In the present embodiment, the temperature T_0 is set at 120°C. As for the refrigerant state, in the process from point B to point E, the supercooled liquid state is maintained in the supercooled liquid region SL, and in the process from point E to point C, the supercooled liquid state in the supercooled liquid region SL is changed to the superheated vapor state in the superheated vapor region SS through the wet vapor region WS.

[0051] The process from point C to point D represents adiabatic expansion performed by the expander 114. In this process, the pressure of the refrigerant is lowered from pressure Pb to pressure Pa, the temperature thereof is also lowered, and the superheated vapor state thereof is maintained in the superheated vapor region SS.

[0052] In the process from point D to point A, the process from point D to point F represents isobaric cooling in the condenser 115 and the process from point F to point A represents isobaric cooling in the sub-cooler 117. In the process from point D to point F, by heat exchange with the ambient air, the temperature of the refrigerant is lowered, while the pressure thereof is maintained at Pa. In the process from point F to point A, by heat exchange with the ambient air, the temperature thereof is further lowered, while the pressure thereof is maintained at Pa. In this case, the refrigerant state changes from the superheated vapor state in the superheated vapor region SS to the saturated liquid state in the process from point D to point F, and changes from the saturated liquid to the supercooled liquid state in the supercooled liquid region SL in the process from point F to point A.

[0053] Where the load on the engine 10 rises, the amount of heat in the exhaust gas increases and the temperature thereof rises, the amount of heat absorbed by the refrigerant from the exhaust gas in the waste gas boiler 113 increases and the enthalpy of the refrigerant after the heat exchange with the exhaust gas also increases. Since the rotational speeds of the pump 111 and the expander 114 are interlocked with that of the engine 10 and are respectively constant, the state of the refrigerant that has been in point C after the heat exchange in the waste gas boiler 113 transforms to be in point C1 in the direction of increasing enthalpy, that is, the direction of rising temperature, for example, along an isopycnic line (equal-specific-volume line) d0 passing through point C. In the state transformation from point C to point C1, the increase in temperature is large. Accordingly, in the Rankine cycle 101, when the exhaust gas temperature rises, in order to inhibit the increase in the temperature of the refrigerant after the heat exchange in the waste gas boiler 113, that is, the refrigerant sucked into the expander 114 and reduce the amount of heat provided to the expander 114, the following control is performed.

[0054] In the isopycnic lines d0, d1, d2, d3, d4 and d5 in FIG. 2, the density increases from d0 towards d5, but the specific volume conversely decreases. Further, the curve To in FIG. 2 represents an isotherm with a temperature To. In the isotherms, the temperature increases by 10°C from the isotherm To towards isotherms T_1, T_2, T_3, T_4, T_5, T_6, T_7, and the temperature decreases by 10°C from the isotherm To towards isotherms T_{-1}, T_{-2}, T_{-3}, T_{-4}, T_{-5}.

[0055] In this case, the ECU 140 performs control such that the temperature of the refrigerant after the heat exchange in the waste gas boiler 113 and the pressure of the refrigerant flowing through the waste gas boiler 113, that is, the temperature and pressure of the refrigerant sucked into the expander 114, change while satisfying the relationship along the target pressure line TPL. Thus, the ECU 140 performs control such that the temperature and pressure of the refrigerant satisfy the relationship along the target pressure line TPL by adjusting the pressure of the refrigerant sucked into the expander 114 correspondingly to the temperature of the refrigerant sucked into the expander 114. In the forementioned case where the amount of heat absorbed by the refrigerant from the exhaust gas in the waste gas boiler 113 increases and the refrigerant state is to change from point C to point C1, the ECU 140 performs the control to change the refrigerant state from point C to point C1'. The enthalpy of the refrigerant in point C1' is less and the refrigerant temperature therein is lower than those in point C1, but with the refrigerant pressure being controlled at a high level, the refrigerant flow rate increases. Hence, the amount of heat received by the refrigerant (working fluid) from the exhaust gas (heat medium) is almost equal to that in point C1.

[0056] The target pressure line TPL is a straight line set such that the refrigerant density increases following the increase in the refrigerant temperature. The target pressure is proportional to the refrigerant enthalpy. The target pressure line TPL is set to be positioned in the superheated vapor region SS even when the engine 10 is under a low load and the exhaust gas temperature is low (close to the left end on the target pressure line TPL in FIG. 2). Further, where the increase in the refrigerant density (increase in the refrigerant flow rate) following the increase in temperature is small, the effect of the present invention decreases, and where the increase in the refrigerant density is too large, hunting easily occurs and it is difficult to perform control.

[0057] As mentioned hereinabove, in the control such that the temperature and pressure satisfy the relationship along the target pressure line TPL, the degree of increase in the refrigerant pressure following the increase in the refrigerant temperature is increased over that in the uncontrolled state (control-free progress) in which the temperature and pressure satisfy the relationship along the isopycnic line d0. Therefore, the refrigerant flow rate is increased to increase the density of the refrigerant flowing through the waste gas boiler 113 following the increase in the refrigerant temperature. As a consequence, the increase in the refrigerant temperature after the heat exchange in the waste gas boiler 113 in response to the increase in the amount of heat of the exhaust gas is inhibited.

[0058] Further, the ECU 140 controls the temperature and pressure of the refrigerant sucked into the expander 114 to match the target pressure line TPL by using the sensed refrigerant temperature of the temperature sensor 131 and the sensed refrigerant pressure of the pressure sensor 132 in the inlet of the expander 114 in the flow channel section 1d and adjusting the flow rate regulating valve 130 to control the flow rate of the refrigerant in the bypass flow channel 3.

[0059] More specifically, the ECU 140 stores in advance the target pressure (target pressure line TPL) of the refrigerant for the temperature sensed by the temperature sensor 131. Then, the ECU 140 adjusts the flow rate regulating valve 130 so that the sensed pressure of the pressure sensor 132 becomes the target pressure. Thus, when the sensed pressure of the pressure sensor 132 is lower than the target pressure, the ECU 140 decreases the opening of the flow rate regulating valve 130 to increase the refrigerant flow rate in the flow channel section 1d, thereby increasing the refrigerant pressure (pressure of the refrigerant sucked into the expander 114) in the flow channel section 1d. When the sensed pressure of the pressure sensor 132 is higher than the target pressure, the ECU 140 increases the opening of the flow rate regulating valve 130 to decrease the refrigerant flow rate in the flow channel section 1d, thereby decreasing the refrigerant pressure (pressure of the refrigerant sucked into the expander 114) in the flow channel section 1d. The ECU 140 then controls the refrigerant pressure correspondingly to the temperature received from the temperature sensor 131 with the passage of time.

[0060] The ECU 140 may calculate the target pressure line TPL from the temperature of the refrigerant in point C, etc.

[0061] Further, in the Rankine cycle 101, the upper limit pressure Pc may be set as a designed upper limit pressure for the flow channel piping of the first flow channel 1, which is a high-pressure-side flow channel, the expander 114, the cooling water boiler 112 and the waste gas boiler 113, which are the constituent elements on the first flow channel 1, etc. In this case, where the refrigerant temperature rises to or above a temperature T5 corresponding to the upper limit pressure Pc on the target pressure line TPL, the target pressure is fixed to the upper limit pressure Pc, as shown by a dashed line TPL'.

[0062] Also, when the temperature of the exhaust gas decreases and the temperature of the refrigerant sucked into the expander 114 decreases below the temperature To at point C, the ECU 140 controls the refrigerant pressure in the pressure sensor 132 so that the relationship between the temperature and pressure of the refrigerant changes along the target pressure line TPL correspondingly to the decreasing refrigerant temperature in the temperature sensor 131. In the control in which the temperature and pressure satisfy the relationship along the target pressure line TPL, the ECU 140 decreases the refrigerant flow rate in order to reduce the density of the refrigerant flowing through the waste gas boiler 113 following the decrease in the refrigerant temperature by comparison with the refrigerant density in the state of the refrigerant in which the refrigerant temperature decreases, while the temperature and pressure continue satisfying the relationship on the isopycnic line d0. Therefore, the decrease in temperature of the refrigerant after the heat exchange in the waste gas boiler 113 in response to the decrease in the amount of heat of the exhaust gas is inhibited and liquid back in the expander 114 is inhibited.

[0063] As mentioned above, in the Rankine cycle 101 according to the embodiment of the present invention, the waste gas boiler 113 that implements heat exchange between the refrigerant and exhaust gas, the expander 114 that generates driving power by expanding the refrigerant, the condenser 115 that condenses the refrigerant and the pump 111 that transfers the refrigerant to the waste gas boiler 113 are provided in the order of description in the circulation path of the refrigerant, and the state of the refrigerant after the heat exchange with the exhaust gas in the waste gas boiler 113 is superheated vapor. The Rankine cycle 101 includes the temperature sensor 131 that senses the temperature of the refrigerant flowing out of the waste gas boiler 113, the pressure sensor 132 that senses the pressure of the refrigerant flowing through the waste gas boiler 113, the bypass flow channel 3 and the flow rate regulating valve 130 that adjust the flow rate of the refrigerant to the waste gas boiler 113, and the ECU 140 that controls the flow rate regulating valve 130. The ECU 140 controls the flow rate regulating valve 130 so that the refrigerant density increases following the increase in the refrigerant temperature when the sensed temperature of the temperature sensor 131 rises.

[0064] In this case, in the refrigerant in the superheated vapor state after the heat exchange in the waste gas boiler 113, the absorbed heat (enthalpy) increases following the increase in the temperature of the exhaust gas implementing the heat exchange. According to this increase in enthalpy, the pressure and temperature of the refrigerant sucked into the expander 114 are assumed to change in the direction of increasing along the isopycnic line d0 in the superheated vapor region SS. The ECU 140 performs control such that the temperature and pressure of the refrigerant sucked into the expander 114 change while satisfying the relationship along the target pressure line TPL where the target pressure is set so that the refrigerant density increases following the increase in the refrigerant temperature. Therefore, since the control is performed to increase the refrigerant flow rate flowing through the waste gas boiler 113 in order to increase the refrigerant density when the exhaust gas temperature rises, the amount of heat absorbed from the exhaust gas in the waste gas boiler 113 can be increased, while the increase in the refrigerant temperature is inhibited. In other words, in the Rankine cycle 101, the increase in the refrigerant temperature in response to the increase in the exhaust gas temperature (increase in heat exchange amount) in the heat exchange between the refrigerant and the exhaust gas can be inhibited.

[0065] Further, in the Rankine cycle 101, the ECU 140 controls the flow rate regulating valve 130 so that the refrigerant density decreases following the decrease in the refrigerant temperature when the sensed temperature of the temperature sensor 131 decreases. In this case, the ECU 140 performs the control such that the temperature and pressure of the refrigerant sucked into the expander 114 change while satisfying the relationship along the target pressure line TPL. As a result, the decrease in the refrigerant temperature after the heat exchange in the waste gas boiler 113 in response to the decrease in the heat amount of the exhaust gas is inhibited, and it is inhibited that refrigerant returning back to a liquid state flows into the expander 114.

[0066] Further, in the Rankine cycle 101, the ECU 140 controls the flow rate of the refrigerant flowing through the waste gas boiler 113 and reduces the refrigerant density so that the sensed pressure of the pressure sensor 132 is maintained at the upper limit pressure Pc when the sensed temperature of the temperature sensor 131 increases to the temperature T5 corresponding to the upper limit pressure Pc or by a larger temperature. As a result the flow channel piping of the first flow channel 1, which is a high-pressure-side flow channel, and the expander 114, the cooling water boiler 112 and the waste gas boiler 113, which are the constituent elements on the first flow channel 1, etc., can be kept from being exposed to an abnormally high pressure.

[0067] Further, in the Rankine cycle 101, the bypass flow channel 3 communicates the flow channel section 1a of the refrigerant extending from the pump 111 towards the waste gas boiler 113 with the second flow channel 2 of the refrigerant extending from the expander 114 towards the pump 111. As a result, the entire refrigerant heated in the waste gas boiler 113 flows into the expander 114, and therefore the thermal energy of the refrigerant acquired in the waste gas boiler 113 can be converted into expansion energy and used in the expander 114 without being wasted along the way. Accordingly, the Rankine cycle 101 can effectively use the thermal energy acquired by the waste gas boiler 113.

[0068] Further, in the Rankine cycle 101, the bypass flow channel 3 is connected between the condenser 115 and the pump 111 in the second flow channel 2 of the refrigerant extending from the expander 114 towards the pump 111. As a result, the refrigerant flowing through the bypass flow channel 3 flows to the downstream of the condenser 115. Therefore, the increase in the refrigerant pressure in the flow channel section 2a between the expander 114 and the condenser 115 can be inhibited without increasing the pressure loss in the condenser 115. Accordingly, since a large difference in the refrigerant pressure between the flow channel section 1d upstream of the expander 114 and the flow channel section 2a downstream of the expander 114 can be ensured, it is possible to ensure sufficient regenerated energy obtained in the expander 114. Further, the bypass flow channel 3 connected between the condenser 115 and the sub-cooler 117 can prevent pump cavitation (foaming of the refrigerant) that occurs when the flow channel section 1a is bypassed to the flow channel section 2d between the sub-cooler 117 and the pump 111. In addition, the bypass flow channel 3 connected between the condenser 115 and the pump 111 can prevent the decrease in the temperature of the refrigerant flowing into the condenser 115 that occurs when the flow channel section 1a is bypassed to the flow channel section 2a between the expander 114 and the condenser 115. As a result, the decrease in the amount of heat radiated in the condenser 115 due to the decrease in the temperature of the inflowing refrigerant can be inhibited. The decrease in the heat radiation amount in the condenser 115 increases the pressure in the second flow channel 2 and decreases the difference in the refrigerant pressure between the flow channel section 1d upstream of the expander 114 and the flow channel section 2a downstream of the expander 114. Therefore, the regenerated energy obtained in the expander 114 is decreased.

[0069] In the Rankine cycle 101 of the embodiment, the target pressure line TPL is a straight line along which the target pressure is proportional to the refrigerant enthalpy, but the target pressure line is not limited to a straight line.

[0070] Further, in the embodiment, the sensed pressure of the pressure sensor 132 (pressure of the refrigerant flowing through the waste gas boiler 113) is adjusted by adjusting the cross-sectional area of the bypass flow channel 3 by means of the flow rate regulating valve 130, but the configuration is not limited thereto.

[0071] As in the Rankine cycle 201 shown in FIG. 3, the pump 111 may be driven by a motor 222, rather than being connected to the engine 10, alternator 118 and expander 114,. In this case, the rotational speed of the pump 111 can be adjusted by controlling the rotational speed of the motor 222, thereby enabling the adjustment of the sensed pressure of the pressure sensor 132. In this case, a drive shaft 114a of the expander 114 and the pulley 119b, which is rotationally driven by the engine 10, are connected by the electromagnetic clutch 119a, and the drive shaft 114a is shared by the alternator 118.

[0072] Further, as in the Rankine cycle 301 shown in FIG. 4, the pump 111 may be driven by the motor 222 instead of being connected to the engine 10, the alternator 118, and the expander 114, and the expander 114 and the alternator 118 may be connected to each other by the drive shaft 114a without being connected to the engine 10. In this case, the rotational speed of the pump 111 can be adjusted by controlling the rotational speed of the motor 222, or the rotational speed of the expander 114 can be adjusted by controlling the load on the alternator 118, thereby enabling the adjustment of the sensed pressure of the pressure sensor 132.

[0073] Further, an expander with a randomly variable intake capacity can be used as the expander 114. In this case, the flow rate (volume flow rate) of the refrigerant transferred by the expander 114 is changed by varying the intake capacity. As a result, since the refrigerant pressure in the flow channel upstream of the expander 114 is changed, it is possible to adjust the sensed pressure of the pressure sensor 132.

[0074] Further, in the Rankine cycle 101 of the embodiment, the bypass flow channel 3 communicates the flow channel section 1a of the first flow channel 1 with the flow channel section 2b of the second flow channel 2, but the configuration is not limited thereto. The bypass flow channel 3 may also be connected to any of the flow channel sections 2a, 2c and 2d in the second flow channel 2.

[0075] Further, a plurality of bypass flow channels 3 may be provided in the Rankine cycle 101 of the embodiment.

[0076] The Rankine cycle 101 of the embodiment is provided with two heat exchangers, namely, the cooling water boiler 112 and the waste gas boiler 113, but the configuration is not limited thereto. Three or more heat exchangers may be provided. The Rankine cycle 101 may be provided with a heat exchanger for heat exchange between the refrigerant of an air conditioner and the refrigerant of the Rankine cycle 101, and with a heat exchanger for heat exchange between the cooling water for a motor used in a hybrid car and the refrigerant of the Rankine cycle 101.

EXPLANATION OF REFERENCE NUMERALS

[0077] 3 - bypass flow channel (flow rate adjusting means); 101, 201, 301 - Rankine cycles; 111 - pump (fluid pumping device); 113 - waste gas boiler (heat exchanger); 114 - expander (fluid expander); 115 - condenser (condensing unit); 130 - flow rate regulating valve (flow rate adjusting means); 131 - temperature sensor (temperature detector); 132 - pressure sensor (pressure detector); 140 - ECU (control device)

Claims

1. A Rankine cycle where, in a circulation path of a working fluid, a heat exchanger that implements heat exchange between the working fluid and a heat medium, a fluid expander that generates driving power by expanding the working fluid, a condensing unit that condenses the working fluid and a fluid pumping device that transfers the working fluid to the heat exchanger are provided in order, wherein a state of the working fluid after the heat exchange with the heat medium in the heat exchanger is superheated vapor, the Rankine cycle comprising:

a temperature detector that detects a temperature of the working fluid flowing out of the heat exchanger;
a pressure detector that detects a pressure of the working fluid flowing through the heat exchanger;
flow rate adjusting means for adjusting a flow rate of the working fluid into the heat exchanger; and
a control device that controls the flow rate adjusting means, wherein
the control device sets a target pressure such that a density of the working fluid flowing out of the heat exchanger increases following an increase in the temperature detected by the temperature detector, and controls the flow rate adjusting means so that the detected pressure of the pressure detector becomes the target pressure.

2. The Rankine cycle according to claim 1, wherein, following the increase in the temperature detected by the temperature detector, the control device controls the flow rate adjusting means to increase the flow rate of the working fluid into the heat exchanger.

3. The Rankine cycle according to claim 2, wherein an upper limit pressure is set for the target pressure, and when the temperature detected by the temperature detector is equal to or higher than a predetermined temperature, the flow rate adjusting means is controlled so that the detected pressure of the pressure detector becomes the upper limit pressure.

4. The Rankine cycle according to any one of claims 1 to 3, wherein the target pressure is proportional to an enthalpy of the working fluid flowing out of the heat exchanger.

5. The Rankine cycle according to any one of claims 1 to 4, wherein
the flow rate adjusting means comprises:

a bypass communicating the flow path of the working fluid, which extends from the fluid pumping device towards the heat exchanger, with the flow path of the working fluid, which extends from the fluid expander towards the fluid pumping device; and

a flow rate regulating valve capable of adjusting the flow rate of the working fluid in the bypass.

6. The Rankine cycle according to claim 5, wherein the bypass is connected between the condensing unit and the fluid pumping device on the flow path of the working fluid extending from the fluid expander towards the fluid pumping device.

Amended claims under Art. 19.1 PCT

1. A Rankine cycle where, in a circulation path of a working fluid, a heat exchanger that implements heat exchange between the working fluid and a heat medium, a fluid expander that generates driving power by expanding the working fluid, a condensing unit that condenses the working fluid and a fluid pumping device that transfers the working fluid to the heat exchanger are provided in order, wherein a state of the working fluid after the heat exchange with the heat medium in the heat exchanger is superheated vapor, the Rankine cycle comprising:

a temperature detector that detects a temperature of the working fluid flowing out of the heat exchanger;
a pressure detector that detects a pressure of the working fluid flowing through the heat exchanger;

flow rate adjusting means for adjusting a flow rate of the working fluid into the heat exchanger; and

a control device that controls the flow rate adjusting means,

wherein the control device sets a target pressure such that a density of the working fluid flowing out of the heat exchanger increases following an increase in the temperature detected by the temperature detector, and controls the flow rate adjusting means so that the detected pressure of the pressure detector becomes the target pressure, and

wherein, following the increase in the temperature detected by the temperature detector, the control device controls the flow rate adjusting means to increase the flow rate of the working fluid into the heat exchanger.

2. (deleted)

3. The Rankine cycle according to claim 1, wherein an upper limit pressure is set for the target pressure, and when the temperature detected by the temperature detector is equal to or higher than a predetermined temperature, the flow rate adjusting means is controlled so that the detected pressure of the pressure detector becomes the upper limit pressure.

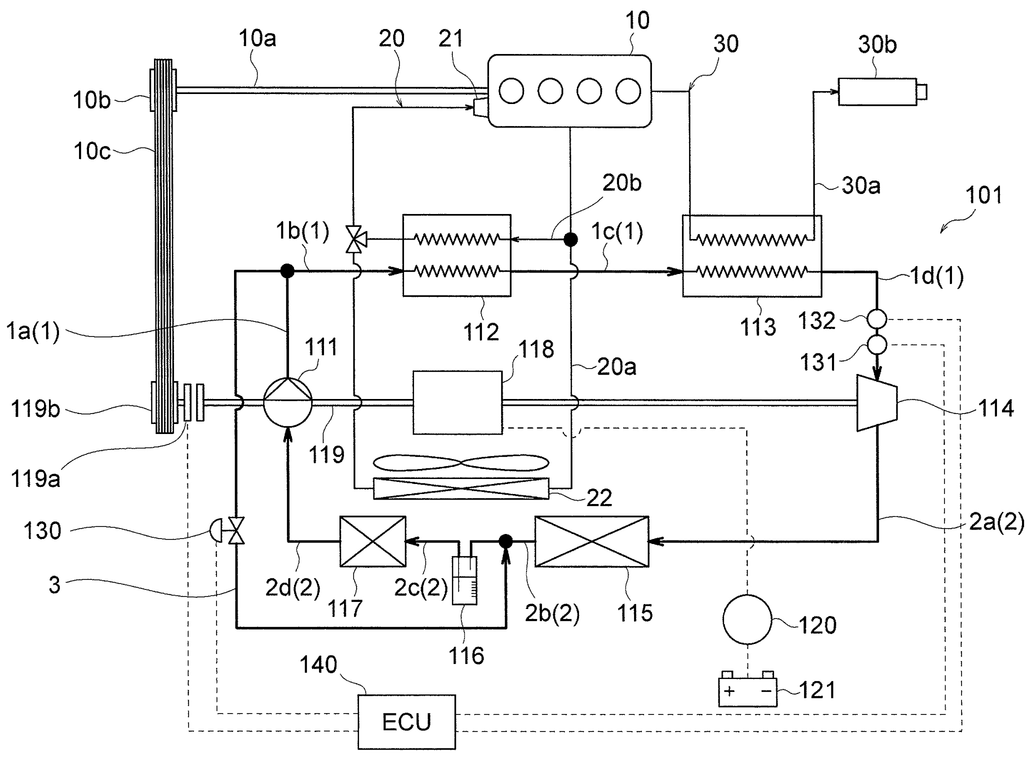
4. The Rankine cycle according to claim 1 or 3, wherein the target pressure is proportional to an enthalpy of the working fluid flowing out of the heat exchanger.

5. The Rankine cycle according to any one of claims 1, 3 and 4, wherein
the flow rate adjusting means comprises:

a bypass communicating the flow path of the working fluid, which extends from the fluid pumping device towards the heat exchanger, with the flow path of the working fluid, which extends from the fluid expander towards the fluid pumping device; and

a flow rate regulating valve capable of adjusting the flow rate of the working fluid in the bypass.

6. The Rankine cycle according to claim 5, wherein the bypass is connected between the condensing unit and the fluid pumping device on the flow path of the working fluid extending from the fluid expander towards the fluid pumping device.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132
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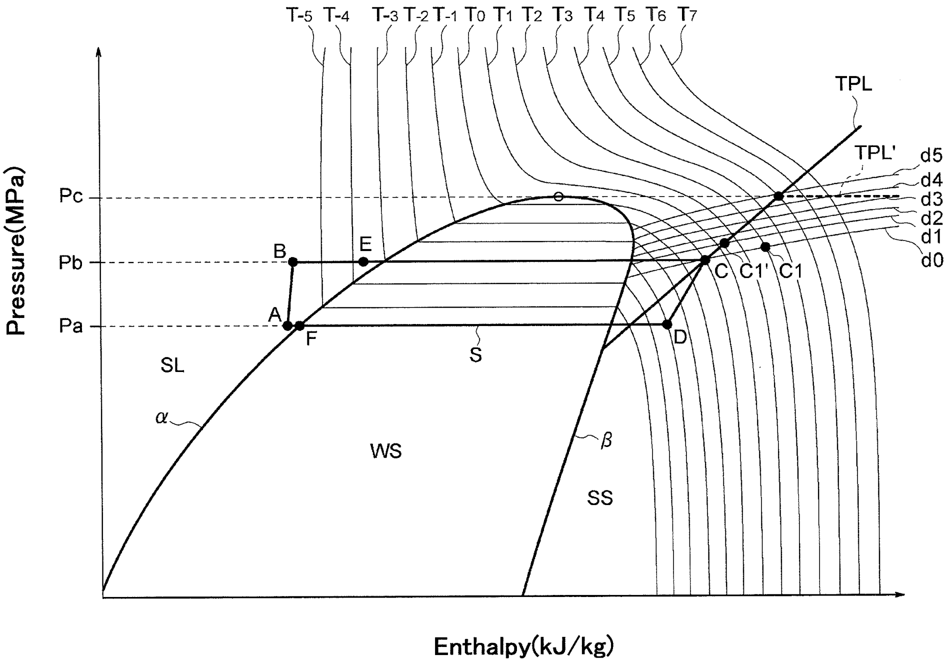
FIG.1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TPL'
d5
d4
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d2
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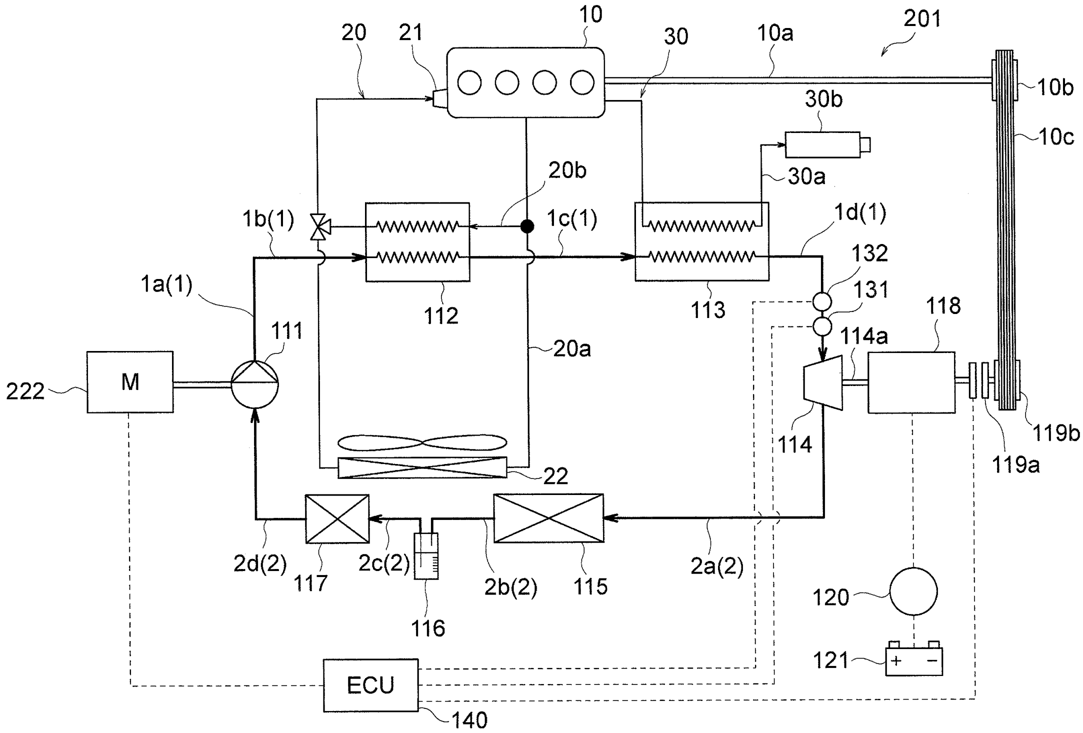
d0
Pressure(MPa)
Pc
Pb
Pa
B
E
A
F
C
C1'
C1
D
S
SL
α
WS
β
SS
Enthalpy(kJ/kg)

FIG.2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114a
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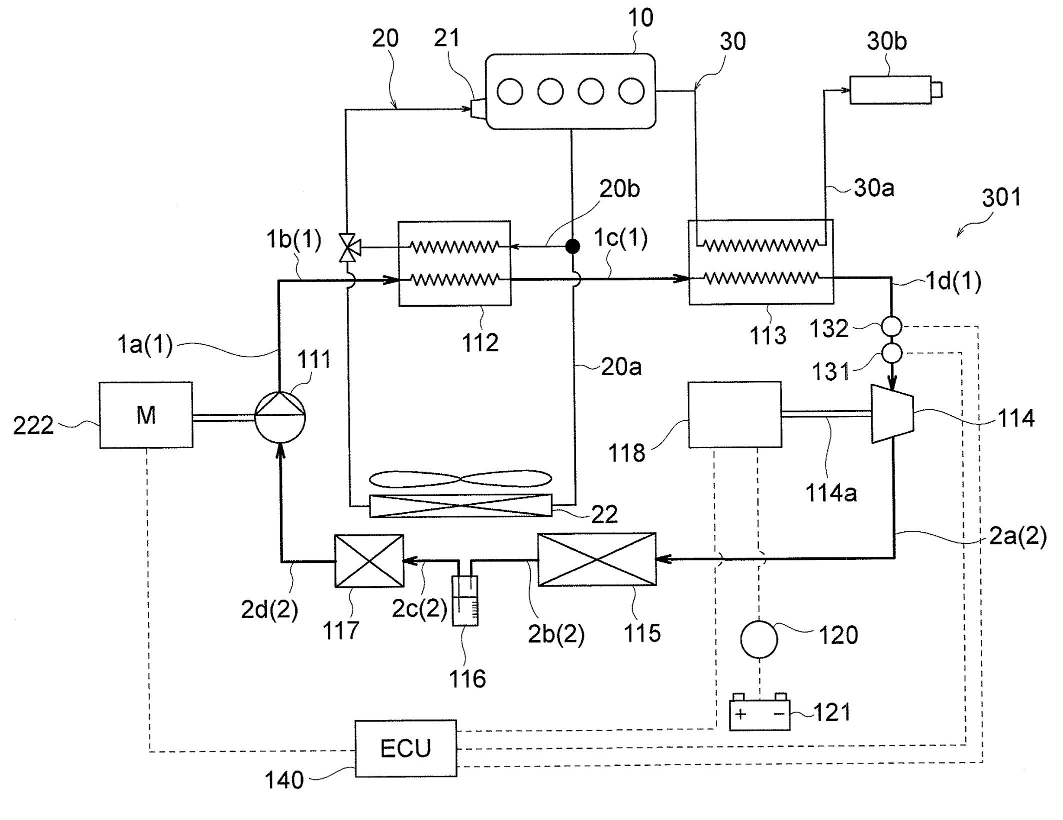
ECU
140

FIG.3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ECU
140

FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/064991

A. CLASSIFICATION OF SUBJECT MATTER
F01K13/02(2006.01)i, *F01K23/02*(2006.01)i, *F01K23/10*(2006.01)i, *F02G5/00*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01K13/02, F01K23/02, F01K23/10, F02G5/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 2010-048129 A (Sanden Corp.), 04 March 2010 (04.03.2010), paragraphs [0021] to [0040], [0043] to [0048]; fig. 1 to 3 (Family: none)	1,4 5,6 2,3
Y	JP 2010-174848 A (Mitsubishi Electric Corp.), 12 August 2010 (12.08.2010), paragraphs [0014] to [0027]; fig. 1 (Family: none)	5,6
Y	JP 2005-325746 A (Toyota Industries Corp.), 24 November 2005 (24.11.2005), paragraph [0009]; fig. 1 (Family: none)	5,6

☒ Further documents are listed in the continuation of Box C.　☐ See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 07 August, 2012 (07.08.12)	Date of mailing of the international search report 21 August, 2012 (21.08.12)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/064991

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-060462 A (Honda Motor Co., Ltd.), 26 February 2004 (26.02.2004), entire text; all drawings & US 2006/0101821 A1 & EP 1536105 A1 & WO 2004/011777 A1 & AU 2003248085 A	1-6
A	WO 2009/101977 A1 (Sanden Corp.), 20 August 2009 (20.08.2009), entire text; all drawings & US 2010/0307155 A1 & EP 2249017 A1	1-6
A	JP 2007-154800 A (Denso Corp.), 21 June 2007 (21.06.2007), entire text; all drawings & US 2007/0126236 A1 & DE 102006055921 A	1-6

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